METHODS TO EXTRACT INFORMATION FROM NOISY DATA

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Award # N0001497WX30219

LONG-TERM GOALS

The long-term goal of this project is to detect weak random signals that have little or no known structure. Furthermore, this is intended to be accomplished in near-optimum fashion with practical realistic processor forms.

OBJECTIVES

The major scientific objective of this investigation is to maximize the processor's signal detection probability while maintaining a specified (low) false alarm probability. Furthermore, the losses of practical processors are to be compared with the fundamental detection limits possible in the noisy environment of interest. This work is supported by ONR Biological Oceanography (Code 322BC).

APPROACH

The technical approach is based upon the body of statistical communication theory as it applies to detection problems encountered in typical underwater acoustic scenarios, where signal processors are forced to function in the presence of unknown behavior and incomplete statistical information.

WORK COMPLETED

A number of different tasks were undertaken and completed in FY97. The major results, as outlined in the abstracts of three NUWC Division Newport technical reports, are listed below:

NUWC-NPT Technical Report 10,760: "Performance of Power-Law Processor with Normalization for Random Signals of Unknown Structure," 5 May 1997.

A signal (if present) is located somewhere in a band of frequencies characterized by a total of N search bins, along with uniform noise of unknown level per bin, $\underline{N}$. The signal occupies an arbitrary set of $\underline{M}$ of these bins, where not only is the extent $\underline{M}$ unknown, but, in addition, the locations of the particular $\underline{M}$ bins occupied by the signal (if present) are unknown. Also, the average signal level in an occupied bin, $\underline{S}$, is arbitrary and unknown.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **Methods to Extract Information from Noisy Data**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Undersea Warfare Center,1176 Howell Street,Newport,RI,02841**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

In order to realize a specified false alarm probability, the power-law processor has been normalized by division with an estimate of the noise level, either from a noise-only reference or from the measured data itself. Various combinations of normalizer forms have been investigated quantitatively through their receiver operating characteristics.

It has been found that if the number of bins, $\underline{M}$, occupied by the signal is small relative to the search size N, the additional signal-to-noise ratio required by the normalizer, in order to maintain the standard operating point, is not significant. However, if $\underline{M}$ is of the order of N/4 or larger, the degradations begin to become substantial. A partial remedy for the inherent losses caused by an unknown noise level is the use of a noise-only data reference, if available. However, eventually, as $\underline{M}$ increases and tends to N, the detection situation becomes progressively more difficult, finally becoming impossible. This is not a limit of the normalized power-law processor, but, rather, of the fact that detection of a white signal in white noise of unknown level is a theoretical impossibility.

A major problem arises with some signal processor forms when the background noise level is unknown. Namely, the actual false alarm probability realized in operation is unknown. Although the receiver operating characteristics of a particular near-optimum processor (such as the power-law processor) may indicate that good detectability performance is achievable, the actual operating point will be unknown. Changing the decision threshold may slide the operating point along a good receiver operating characteristic, but the precise location being utilized will be unknown. The normalizer forms suggested here remedy this limitation for the power-law processor by guaranteeing a prespecified false alarm probability, although at the (unavoidable) expense of a slight loss in detectability.

NUWC-NPT Technical Report 10,822: "Detection Capability of Linear-and-Power Processor for Random Burst Signals of Unknown Location," 25 August 1997.

A random signal (if present) is located somewhere in a time interval characterized by a total of N search bins, along with uniform noise. The signal is burstlike and occupies a contiguous set of M bins, but the location of the M bins occupied by the signal is unknown. Also, the average signal level S in an occupied bin is arbitrary and unknown.

The optimum (likelihood ratio) processor for this scenario is derived and simulated to determine its receiver operating characteristics. Practical approximations to this likelihood ratio processor lead to a class of suboptimum processors, called the linear-and-power (LAP) processors, which have a control parameter μ that can be varied for the best signal detection capability. Simulations of various LAP processors reveal that near-optimum performance can be achieved by letting the control parameter μ tend to infinity; the resultant processor, called the "maximum" processor, compares the maximum of all possible partial contiguous linear sums of the observations with a fixed threshold. For search size N = 1024, the loss in detectability of the maximum processor relative to the unrealizable likelihood ratio processor is less than 0.1 dB over the complete range of values of M, which is the signal burst size.

NUWC-NPT Technical Report 10,840: "Evaluation of Small Tail Probabilities Directly from the Characteristic Function," 15 September 1997.

An efficient and accurate fast Fourier transform technique for obtaining small tail probabilities for both the probability density function and the exceedance distribution function, directly from the characteristic function, is derived and demonstrated numerically for several examples. The method is especially useful when analytic or asymptotic expressions for the probabilities are unavailable or unknown.

By choosing the contour shift parameter close to the highest singularity of the characteristic function in the complex plane, very small values of the tail probabilities of the density function and exceedance distribution function can be realized. The limitation in this approach is that the sampling increment must then be small, in order to avoid aliasing. Such finer sampling necessitates more computer time and effort, but it does not require more storage; rather, prealiasing can be advantageously employed to keep the fast Fourier transform size at reasonable values. The fast Fourier transform size has no effect upon the errors caused by aliasing and truncation, but merely controls the spacing at which the probability density function and exceedance distribution function outputs are calculated. Tail probabilities in the E-50 range are readily available with a computer limited to 15 significant decimal digits.

RESULTS

It is sometimes possible to obtain a practical processor that performs near optimum by modifying the (optimum) likelihood ratio processor as little as possible, but yet eliminating its dependence on any unknown signal or noise parameters. The exact procedure is very example dependent; no general rules are known.

IMPACT

The major impact of the new detectability results above is that tight bounds on attainable performance can be realized by practical processor forms for a number of realistic scenarios in which processors must function with limited knowledge.

TRANSITIONS

The results of this study have received immediate application in the detection of noiselike targets, which is a major task undertaken by the transient group, Code 2121, at the Naval Undersea Warfare Center Division in Newport, RI. In particular, the power-law processor outperforms the current transient detector by several decibels.

RELATED PROJECTS

REFERENCES

A. H. Nuttall, "Performance of Power-Law Processor with Normalization for Random Signals of Unknown Structure," NUWC-NPT Technical Report 10,760, Naval Undersea Warfare Center Division, Newport, RI, 5 May 1997.

A. H. Nuttall, "Detection Capability of Linear-and-Power Processor for Random Burst Signals of Unknown Location," NUWC-NPT Technical Report 10,822, Naval Undersea Warfare Center Division, Newport, RI, 25 August 1997.

A. H. Nuttall, "Evaluation of Small Tail Probabilities Directly from the Characteristic Function," NUWC-NPT Technical Report 10,840, Naval Undersea Warfare Center Division, Newport, RI, 15 September 1997.